N69-34380
~~AS~~ NASA CR-101806

CONTRACT NAS 9-9357

BIOMEDICAL DATA GROUND LEAD SYSTEM

FINAL REPORT

LMSC/687932

JULY 31, 1969

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

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CR 101806

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1.0 SUMMARY

1.1 Purpose

This Biomedical Ground Lead System is intended to prevent dangerous values of electric current from flowing through an astronatu's ground electrode, while providing a low resistance path to ground for draining static charge, and providing electrical ground reference for bioinstrumentation.

1.2 Hardware

Five breadboard units and 24 engineering prototype units were built, tested and delivered to NASA. One additional engineering prototype unit will be integrated into a GFE sternal harness when written instructions defining the desired configuration have been received from NASA.

1.3 Tests

Destructive and other tests were performed on 25 breadboard units to determine their behavior under exceptionally severe electrical stress.

1.4 Safety and Reliability

An analysis was performed resulting in a predicted reliability of 99.7%. Suggestions are made for enhancing this reliability. A failure mode analysis is also included.

1.5 Future Requirements

A method has been proposed for incorporating a unit in the ground electrode of an astronaut's sternal harness.

2.0 INTRODUCTION

2.1 Delineation of the Problems to be Solved

There are several circumstances relating to electrical phenomena which are troublesome to astronauts. Among them are: the danger of shocks due to accidental contact with voltage sources, the discharge of a large static charge which is often manifested in a spark, and the buildup of a large static charge which might exceed the common mode range of bioinstrumentation amplifiers.

If an astronaut were not touching a conductive part of the spacecraft frame (ground) with one part of his body at the time another part of his body accidentally contacted a voltage source, the danger of heavy shock could be minimized by having the astronaut grounded through a large resistance (exceeding 200K ohms). However the buildup of a static charge on the astronaut is best accomplished by having his body continually grounded through a low resistance.

To simultaneously meet both of these conditions, an optimum system would provide a low resistance path for small currents to prevent the build-up of static electricity, and would also limit any current flow to a value well below the astronaut's perception threshold.

2.2 Solution to these Problems

Prior to the award of this contract, Lockheed Missiles & Space Company (LMSC), had performed a series of laboratory experiments with solid state electronic circuits. Off-the-shelf field effect current regulating diodes were investigated but it was found that their characteristics did not meet all of the requirements. Thereupon, development work was performed to employ commercially available components in a circuit which would meet all of the requirements. This was successfully accomplished and LMSC built several working models of a satisfactory current limiting device. This device will hereafter be referred to as a

Biomedical Ground Lead System (BGLS). It consists of a circuit containing two high voltage field effect transistors (FETs), two low pinch-off current FETs and one resistor (See. Figure 1). LMSC subsequently applied for a patent on this circuit.

2.3 Operating Specifications

The BGLS circuit operates in such a manner that for low values of applied voltage, it acts like a resistor having a fixed value not exceeding 12,000 ohms. However, as the applied voltage is increased, the fixed resistance no longer pertains. The BGLS instead acts as a device which limits the current to 0.12 milliamperes or less, at applied voltages up to 200 volts, root mean square (VRMS). This is considered to be a safe current; one which astronauts can withstand without physiological injury. As a matter of fact, it is below the perception level of many individuals. The above mentioned limiting values form the basic performance specifications for the BGLS under this contract, for applied voltages in the frequency range of zero to 10,000 Hertz (Hz).

3.0 FABRICATION

3.1 Breadboard Units

Each of these units incorporated one LS41048-S-4330 resistor (3,300 ohms), two Amelco 2N 4882 high voltage FETs in TO 5 cans and two Siliconix FN-1598 low pinch-off FETs in TO 18 cans. An insulating sleeve was placed over each of the cans and each circuit was soldered by LMSC certified solderers, using a fixture to hold the four FETs in their proper positions.

Stranded copper lead wires were attached, and the five units to be delivered to NASA plus five of the test units were encapsulated in epoxy. The size of the encapsulated units is approximately 0.5 x 0.5 x 1.75 inches. The remaining twenty test units were not encapsulated so as to facilitate disassembly and post-mortem analyses after desctuctive testing was completed.

3.2 Engineering Prototype Units

The external physical configuration of these units is a quarter inch square flatpack approximately 0.09inch thick with a gold plated Kovar lead at each end. Internally, the construction is a hybrid microcircuit employing 0.0007 inch diameter gold wire interconnections ultrasonically bonded to the components. The 4,700 ohm resistor is a thick conductive film deposited on a ceramic substrate. The junction type silicon FET chips are bonded to deposited gold film traces with conductive epoxy.

The two high voltage FET chips in each unit are gold backed Amelco 2N 4882D units meeting the following requirements: Drain-source "on" resistance less than 3,000 ohms; at V_{DGO} of 300 volts, I_{DG} must be less than 10 microamperes; Parts inspected per QAI 4-4 to assure high reliability.

The two low pinch-off FET chips in each unit are gold backed Siliconix FN 1767 units subjected to 100% visual examination per PS 4003 Appendix A to obtain high reliability.

A serial number was inscreibed on each flatpack, and after the circuits were completed, they were operated to check function. This was followed by a formal 100% pre-seal visual inspection by LMSC and US Air Force inspectors (since NASA had delegated this function to Air Force Quality Assurance personnel at Sunnyvale). The covers were then sealed onto the flat packs using epoxy, and the units were again functionally checked. Next a "burn in" operation was performed, subjecting each unit to 175 VRMS at 60 Hz continuously for 65 hours. After this a formal functional test was performed in the presence of one LMSC and one US Air Force inspector. All of the contractually required functional parameters were measured and recorded along with the serial number of each unit, and the datasheets were sent to NASA with the units.

3.3 Additional Work

In addition to the 24 unembellished engineering prototype units, one BGLS unit will be integrated into the GFE sternal harness when written instructions defining the desired configuration have been received from NASA.

4.0 SAFETY AND RELIABILITY

4.1 Reliability Prediction

Figure 1 is a schematic diagram of the BGLS circuit. Figure 2 is the reliability model used in making the reliability prediction.

The available statistical failure rate data for microelectronic hybrid circuit devices is based on the first generation of hybrid circuit devices. The rapid advances in the state-of-the-art of microelectronic hybrid circuit devices and their increasing use and high inherent reliability would indicate that when statistical failure rate data become available for the present generation of hybrid circuit devices, they should exhibit lower failure rates than those utilized in the computation of this reliability prediction.

BGLS RELIABILITY PREDICTION

λ of FET die $\quad \lambda_s = \lambda_b (\Pi_E \times \Pi_A \times \Pi_C) + \Sigma_E$

$\lambda_b = .0018$, $\Pi_E = 10.0$, $\Pi_A = 2.0$, $\Pi_C = 1.0$, and $\Sigma_E = 0.005$

Solving: $\lambda_S = .041\%/1000\text{Hrs} = \lambda_{FET}\ .41 \times 10^{-6}/\text{Hr}$

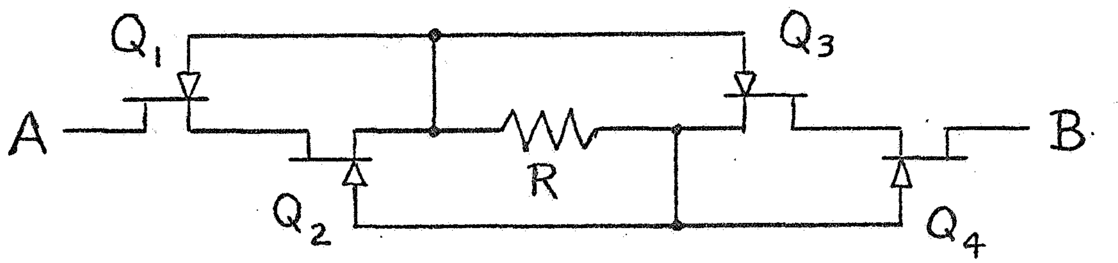
Source: RADC Reliability Notebook Volume II

λ of thick film resistor $\quad \lambda_R = .01\%\ /1000$ Hrs or $\lambda_R = .1 \times 10^{-6}/\text{Hr}$

(Random failure rate @ normal rated power @ 60°C is .01% to .04%/1000 Hrs per Mil-HDBK 217A)

λ of ultrasonic bonded wire joints .001%/1000Hrs (EST.) 18 joints x $.01 \times 10^{-6} = .18 \times 10^{-6}/\text{Hr} = \lambda_{J18}$

FIGURE 1



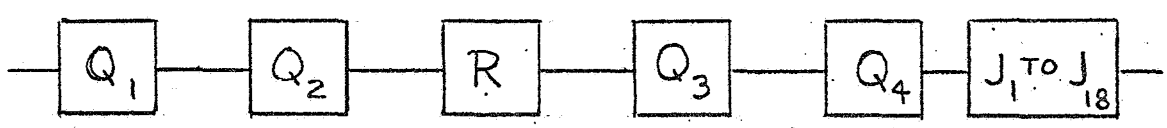
SCHEMATIC DIAGRAM OF BGLS CIRCUIT

(Patent Applied For)

Q_1 and Q_4 are high voltage FET s.

Q_2 and Q_3 are low pinch-off FET s.

FIGURE 2



RELIABILITY MODEL OF BGLS

R_{BGLS} = Reliability of BGLS

λ = Failure Rate

t = Mission Time in Hours = 1344

$$R_{BGLS} = e^{-\lambda t} \cong 1 - \lambda t$$

$$R_{BGLS} = 1 - (R_{Q_1} + R_{Q_2} + R_{Q_3} + R_{Q_4} + R_{R_1} + R_{J_{18}})(t) \times 10^{-6}$$

$$R_{BGLS} = 1 - (.41 + .41 + .41 + .41 + .1 + .18)(1344) \times 10^{-6}$$

$$R_{BGLS} = 1 - .002580 = .99742$$

The lower values of failure rates were used to partially compensate for the passive, normally unpowered, operation of the BGLS and the 70°F (21.1°C) temperature anticipated for the astronaut and the BGLS. Most failure rates are based on normal rated power at 60°C (140°F) temperature levels.

The above analytical study predicts a reliability of 99.742%. However, a reliability of 95% to a confidence level of 70% is demonstrated by testing an entire lot of 25 BGLS to the full rated voltage without any failures. *

4.2 Medical Safety Considerations

A major purpose of the BGLS is to prevent the buildup of large electrostatic potentials between the astronaut and his immediate environment. An electrostatic discharge constitutes a shock hazard, which if it occurs at a critical time in flight, may seriously endanger the mission. Such discharges frequently cause sparks which are especially hazardous in an oxygen atmosphere. The buildup of large electrostatic charges can also interfere with the proper functioning of, or may even damage, biomedical monitoring equipment. Use of the BGLS can preven ordinary electrical shock and accidental electrocution in the event that the astronaut touches a "hot" AC or DC source, the other side of which is grounded to the space vehicle.

By virtue of the unique electrical characteristics of the BGLS, any

*Using data tabulated in NOTS Tech. Memo 113.

electrostatic charge being generated will be drained off instantaneously, while the touching of a "hot" electrical source will result in only a minimal, insensible, and entirely harmless current flow through the astronaut's body, provided that the voltage level of this source is below the peak operating voltage rating of the BGLS.

It must be remembered, however, that the BGLS can only protect the astronaut against ordinary electrical shock if the astronaut is not inadvertently also grounded to his spacecraft by other low resistance ground return paths. Such accidental ground paths can conceivably be established through biomonitoring leads due to the accumulation of perspiration on the lead connectors of body-worn signal conditioners, or even by the condensation of water vapor, mixed with particulate deposits, on the inside of the exhaust hose when the astronaut is dressed in a full pressure suit with the visor of his helmet closed.

The latter possibility could be prevented by the use of a heating element built into the wall of the proximal section of the exhaust tube. Accidental grounding through the biomedical leads can be readily eliminated by installing BGLS devices at the proximal and distal ends of all active biomedical monitoring leads as well as at the distal ends of all (inactive) shields surrounding these leads at the point where they interface with spacecraft equipment.

For the sake of providing the astronauts with optimum protection, LMSC recommends that both of the above suggestions be given serious consideration for future implementation. The possibility of establishing accidental ground return paths by condensed water vapor on the microphone, earphones, sensor for partial pressure of carbon dioxide in the suit, and other transducers should also be evaluated.

FIG. 3

FAILURE MODES AND EFFECTS ANALYSIS					PERCENT PROBABILITY OF OCCURRENCE		
Equipt. Name	Mode of Failure	Cause of Failure	Effect on Sub System	Effect on System	(%)	Shock Current Resulting/Failure	Remarks
Q1 or Q4 Field Effect Transistor (Hi Voltage)	Parameter Change	Degradation	Less severe than short or open	Less severe than short or open	.0275	0 to 34 MA @ 280V	Negligible change to complete loss of electroshock protection
	Shorted	Excessive Current or Voltage	Part destroyed	Catastrophic	.01375	34 MA @ 280V	Protection against fatal electroshock invalidated
	Open	Excessive Current or Voltage			.01375	7.5 MA @ 280V	Protection against minor electroshock invalidated
Q2 or Q3 Field Effect Transistor (Lo Pinch-Off Voltage)	Parameter Change	Degradation	Less severe than short or open	Less severe than short or open	.0275	0 to 34 MA @ 280V	Negligible change to complete loss of protection against minor electroshock
	Shorted	Excessive Current or Voltage	Part destroyed	Catastrophic	.01375	34 MA @ 280V	Protection against fatal electroshock invalidated
	Open	Excessive Current or Voltage			.01375	7.5 MA @ 280V	Protection against minor electroshock invalidated
R_1 Resistor Thick Film	Parameter Change	Degradation	Less Severe than short or open	Less severe than short or open	.00067	10 μA to .06 MA @ 280V	Negligible change to loss of electroshock protection
	Shorted	Excessive Current or Voltage	Part destroyed	Catastrophic	.00013	0.6 MA @ 280V	Loss of protection against electroshock
	Open	Excessive Current or Voltage			.00054	10 μA @ 280V	Loss of Protection against electroshock

FIG.3 (Cont'd.)

FAILURE MODES AND EFFECTS ANALYSIS					PERCENT PROBABILITY OF OCCURRENCE		
Equipt, Name	Mode of Failure	Cause Failure	Effect on Sub System	Effect on System	(%)	Shock Current Resulting/Failure	Remarks
Connections J_1 thru J_{18}	Inter-mittent Contact	Degradation	Minor to major	Minor to major	.00006	0 to 34 MA @ 280V	Neglibible change to loss of electroshock protection
	Shorted	Contami-nation			.00002		
	Open	Defective bonding			.00004	7.5 MA @ 280V	

1. For detailed analysis of single and combined failure modes see stress analysis.
2. Shock current resulting from failures assumes a 280V hazard current to provide a uniform base for comparingfailure effects.

4.3 Failure Modes and Effects Analysis

A summary of failure modes and resultant shock currents are listed below. The component designations relate to the circuit diagram of Figure 1. Since the circuit is bi-directionally symmetrical, failure modes for Q_1 and Q_2 also apply for Q_4 and Q_3, respectively.

r_{dss_1} is the zero gate voltage small signal drain to source resistance of Q_1. (approximately 2,000 ohms)

r_{dss_2} is the zero gate voltage small signal drain to source resistance of Q_2 (approximately 1,000 ohms).

4.3.1 Q_1 drain open circuit

$I = 0$ for both directions

4.3.2 Q_1 gate open circuit

4.3.2.1 For A positive:

This is a shock mode. The current is limited by the open gate current limiting value of Q_1, which approximates the I_{dss} value. For the 2N4882 FETs used in the breadboard BGLS, this current is between 1.5 ma. and 7.5 ma. for voltages through about 280 volts.

4.3.2.2 For B positive

Normal operation

4.3.3 Q_1 source open circuit

4.3.3.1 For A positive

This is not a shock mode. The current is limited to the reverse biased current flowing across the gate-to-drain junction of Q_1. This current will not exceed $10\mu a$ through about 280 volts.

4.3.3.2 For B positive, the limiting action will be normal, but in the operating mode, bioelectrical signals will be blocked, since the bioelectrical voltages are not large enough to forward bias the drain-to-gate junction of Q_1.

4.3.4 Q_1 drain-to-gate short

4.3.4.1 For A positive, this is a shock mode. The current will conform to the following equation:

$$I = \frac{E}{R + r_{dss_1} + r_{dss_2} + R_{external}}$$

Assuming an external resistance (electrode connections and patient body resistance) of 1000 Ω, the current will be approximately

$I = 0.12\ E$

where I is current in milliamperes

E is applied voltage in volts

4.3.4.2 For B positive

Normal Operation

4.3.5 Q_1 source-to-gate short

4.3.5.1 For A positive, this is a shock mode. The current is limited by the I_{dss} value of Q_1. For the 2N 4882 FETs used in the breadboard BGLS, this current is between 1.5 ma. and 7.5 ma. through about 280 volts.

4.3.5.2 For B positive

Normal operation

4.3.6 Q_1 drain-to-source short

4.3.6.1 For A positive, this is a shock mode. Operation will be normal for applied voltages below the drain-to-gate breakdown voltage of Q_2, approximately 70 volts for the FN 1598 FETS used in the BGLS breadboard.

For voltages exceeding the Q_2 breakdown voltage and currents low low enough that Q_2 is not damaged, the current will conform to the following equation:

$$I = I_L + \frac{E - EB2}{R + r\,dss_1 + r\,dss_2 + R\text{external}}$$

Where I_L is the normal limiting current.

Assuming an external resistance of 1,000 ohms, the current is approximately:

$I = 0.1 + 0.12\ (E-70)$

Where: I = current in milliamperes

E = applied voltage in volts

The long term current which will damage Q_2 corresponds to about 300 mw, or for a breakdown of 70 volts, $I = \frac{.3w}{70V} \approx 4.3$ ma

This current will flow at a voltage of approximately 105 volts. Significantly higher transient, impulse, or AC voltages can be applied without damaging Q_2. The effect of a Q_2 failure in conjunction with a Q_1 drain-to-source short depends on the Q_2 failure mode. These will be treated under "Combined Failure Modes", sections 4.3.17 and up.

4.3.6.2 For B positive

Normal operation

4.3.7 Q_2 drain open circuit

This is not a shock mode. The effect is the same as for a Q_1 source open circuit (See section 4.3.3)

4.3.8 Q_2 qate open circuit

4.3.8.1 For A positive, this is a shock mode*. The current is limited by the open gate current limiting value of Q_1, which approixmates the Idss value. For the FN 1598 FETs used in the breadboard BGLS, this current is between 0.2 and 0.6 ma.

4.3.8.2 For B positive

Normal operation

4.3.9 Q_2 source open circuit.

This is not a shock mode. The effect is the same as Q_2 drain open circuit (See section 4.3.7 and section 4.3.3)

4.3.10 Q_2 source-to-gate short circuit

4.3.10.1 For A positive, this is a shock mode. The current is limited by the Idss value of Q_2. For the FN 1598 FETs used in the BGLS breadboard, this current is between 0.2 and 0.6 ma.

4.3.10.2 For B positive, the current is limited by the Idss value of Q_3, which is also 0.2 to 0.6 ma.

4.3.11 Q_2 drain-to-gate short, this is a shock mode.

* Note: 0.2 ma cannot be detected by the average person in normal electrode locations. 0.6 ma can be easily sensed but has a low probability of direct harm.

4.3.11.1 For A positive, the current is limited by the Idss of Q_1, which is between 1.5 ma and 7.5 ma.

4.3.11.2 For B positive, the current is limited by the Idss of Q_3, which is between 0.2 ma and 0.6 ma

4.3.12 Q_2 drain-to-source short. This is a shock mode. The effect is the same as for a Q_1 source-to-gate short (See section 4.3.5)

4.3.13 Q_1 source-to-gate-to-drain short. This is a shock mode. The effect is the same as for a Q_1 drain-to-gate short (See section 4.3.4)

4.3.14 Q_2 source-to-gate-to-drain short. This is a shock mode. The effect is the same as for a Q_2 drain-to-gate short (See section 4.3.11)

4.3.15 R open circuit. This is not a shock mode. The current is equal to the sum of the reverse biased gate-to-drain junction currents of Q_1 and Q_2. This current should not exceed 10 μa for a 280 volt applied voltage.

4.3.16 R short circuit. This is a shock mode. The effect is the same as a Q_2 source-to-gate short (See section 4.3.10).

Combined Failure Modes

In case of a Q_1 drain-to-source short, a normally protected voltage can damage Q_2. The following are the effects of various Q_2 failure modes in conjunction with a Q_1 drain-to-source short.

4.3.17 Q_2 drain open (and Q_1 drain-to-source short). This is not a shock mode. The effect is the same as for a single failure Q_1, source open circuit (See section 4.3.3).

4.3.18 Q_2 source open (and Q_1 drain-to-source short). This is a shock mode.

4.3.18.1 For A positive.

For voltages below the Q_2 drain-to-gate breakdown voltage the effect is the same as for a single failure Q_2 source open (See section 4.3.9) For voltages above the Q_2 drain-to-gate breakdown voltage, the current is the same as for the single failure Q_1 drain-to-source short (See section 4.3.6).

4.3.18.2 For B positive

The effect is the same as for the single failure Q_2 source open (See section 4.3.9).

4.3.19 Q_2 gate open (and Q_1 drain-to-source short). this is a shock mode.

4.3.19.1 For A positive.

For voltages below the Q_2 drain-to-source breakdown voltage, the effect is the same as for the single failure Q_2 gate open (see section 4.3.8).

For voltages above the Q_2 drain-to-source breakdown voltage, the current could increase until a further failure occurs, probably an open.

4.3.19.2 For B positive.

The effect is the same as for the single failure Q_2 gate open (see Section 4.3.8).

4.3.20 R open (and Q_1 drain-to-source short)

4.3.20.1 For A positive.

This is a shock mode. The effect is the same as for the combined failures of Q_1 drain-to-source short and Q_2 source open (See section 4.3.18).

4.3.20.2 For B positive.

The effect is essentially the same as for a single mode failure R open (see section 4.3.15)

4.3.21 R short and Q_1 drain-to-source short.

This is a shock mode.

4.3.21.1 For A positive

For voltages below the Q_2 drain-to-gate breakdown voltage, the effect is essentially the same as for a single failure R short (See section 4.3.16). For voltages greater than the Q_2 drain-to-gate breakdown voltage, the current could increase until a further failure occurs, probably an open.

4.3.21.2 For B positive

This is a shock mode. The effect is essentially the same as for a single failure R short (see section 4.3.16)

4.3.22 Q_2 drain-to-source short (and Q_1 drain-to-source short). This is a shock mode. The effect is the same as for a single failure Q_1 drain-to-gate short (see section 4.3.4)

4.3.23 Q_2 drain-to-gate short (and Q_1 drain-to-source short). This is a shock mode.

4.3.23.1 For A positive

The current can increase until a further failure occurs.

4.3.23.2 For B positive

The effect is essentially the same as for a single failure R short (see section 4.3.21)

4.3.24 Q_1 drain to source short and Q_2 source-to-gate short. This is a shock mode. The effect is the same as for Q_1 drain-to-source short and R short (See section 4.3.29).

4.3.25 Q_1 drain-to-gate short and Q_2 drain open. This is a shock mode. The effect is essentially the same as for a single failure Q_1 drain to-gate short (see section 4.3.4)

4.3.26 :Q_2 source open.

This is a shock mode. The effect is essentially the same as for a single failure Q_1 drain-to-gate short (see section 4.3.4)

4.3.27 :Q_2 gate open. This is a shock mode. The effect is essentially the same as for a single failure Q_1 drain-to-gate short (see section 4.3.4)

4.3.28 :Q_1 drain to gate short and R open

4.3.28.1 For A positive

This is a shock mode. The effect is the same as for the single failure Q_1 drain to gate short except that for voltages below the forward conduction voltage of the Q_3 gate-to-drain junction (approximately 0.6v) the current is reduced (see section 4.3.4)

4.3.28.2 For B positive

The effect is the same as for a single failure R open (See section 4.3.15).

4.3.29 :R short. This is a shock mode. The effect is the same as for a combined Q_1 drain-to-source short and a Q_2 drain-to-gate short. (See section 4.3.23).

4.3.30 Q_1 drain to gate short and:Q_2 drain to source short. This has the same effect as a single failure Q_1 drain-to-gate short (see section 4.3.4)

4.3.31 :Q_2 drain-to-gate short. This has the same effect as a single failure Q_1 drain-to-gate short. (see section 4.3.4)

4.3.32 :Q_2 source-to-gate short. This has the same effect as a combined Q_1 drain-to-source short and a Q_2 drain-to-gate short (see section 4.3.23)

Failure Analysis Summary

Section	Mode
4.3.1	Q_1 drain open
4.3.2	Q_1 gate open
4.3.3	Q_1 source open
4.3.4	Q_1 drain-to-gate short
4.3.5	Q_1 source to gate short
4.3.6	Q_1 drain to source short
4.3.7	Q_2 drain open

4.3.8	Q_2 gate open
4.3.9	Q_2 source open
4.3.10	Q_2 source-to-gate short
4.3.11	Q_2 drain-to-gate short
4.3.12	Q_2 drain-to-source short
4.3.13	Q_1 source-to-gate-to-drain short
4.3.14	Q_2 source-to-gate-to-drain short
4.3.15	R open
4.3.16	R short
4.3.17	Q_1 drain-to-source short and:Q_2 drain open
4.3.18	:Q_2 source open
4.3.19	:Q_2 gate open
4.3.20	:R open
4.3.21	:R. short
4.3.22	:Q_2 drain-to-source short
4.3.23	:Q_2 drain-to-gate short
4.3.24	:Q_2 source-to-gate short
4.3.25	Q_1 drain-to-gate short and:Q_2 drain open
4.3.26	:Q_2 source open
4.3.27	:Q_2 gate open
4.3.28	:R open

4.3.29	R short
4.3.30	Q_2 drain-to-source short
4.3.31	Q_2 drain-to-gate short
4.3.32	Q_2 source-to-gate short

4.4 Suggestions for Increasing Reliability (also, see section 4.2)

Analysis indicates that the BGLS will protect an astronaut from unexpected electroshock hazard with a predicted reliability of .997. Incorporation of a second BGLS in series with the first will increase the reliability to .999993, with respect to protecting the astronaut from lethal amounts of current. The resistance of two BGLS in series, however, would be twice as great.

The adoption of periodic checkout procedures will significantly reduce the possibility of a BGLS remaining in service after a failure has occurred.

Because the BGLS can be damaged by high voltages even though the total electrical energy applied is small, precautions must be taken to avoid exposure to static electricity discharge prior to or during attachment of the BGLS to the astronaut via the grounding electrode. For a further discussion of this, see section 5.

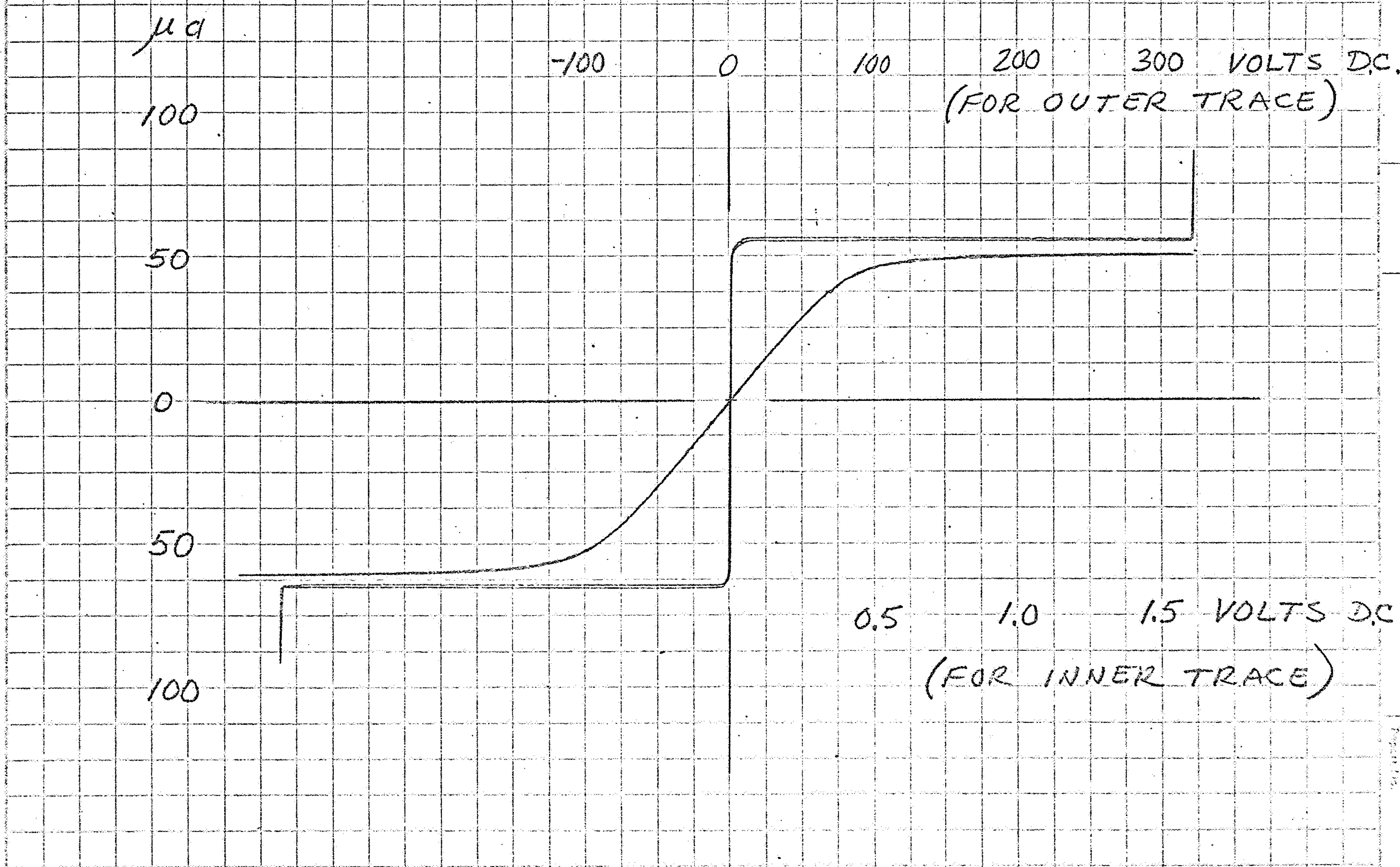
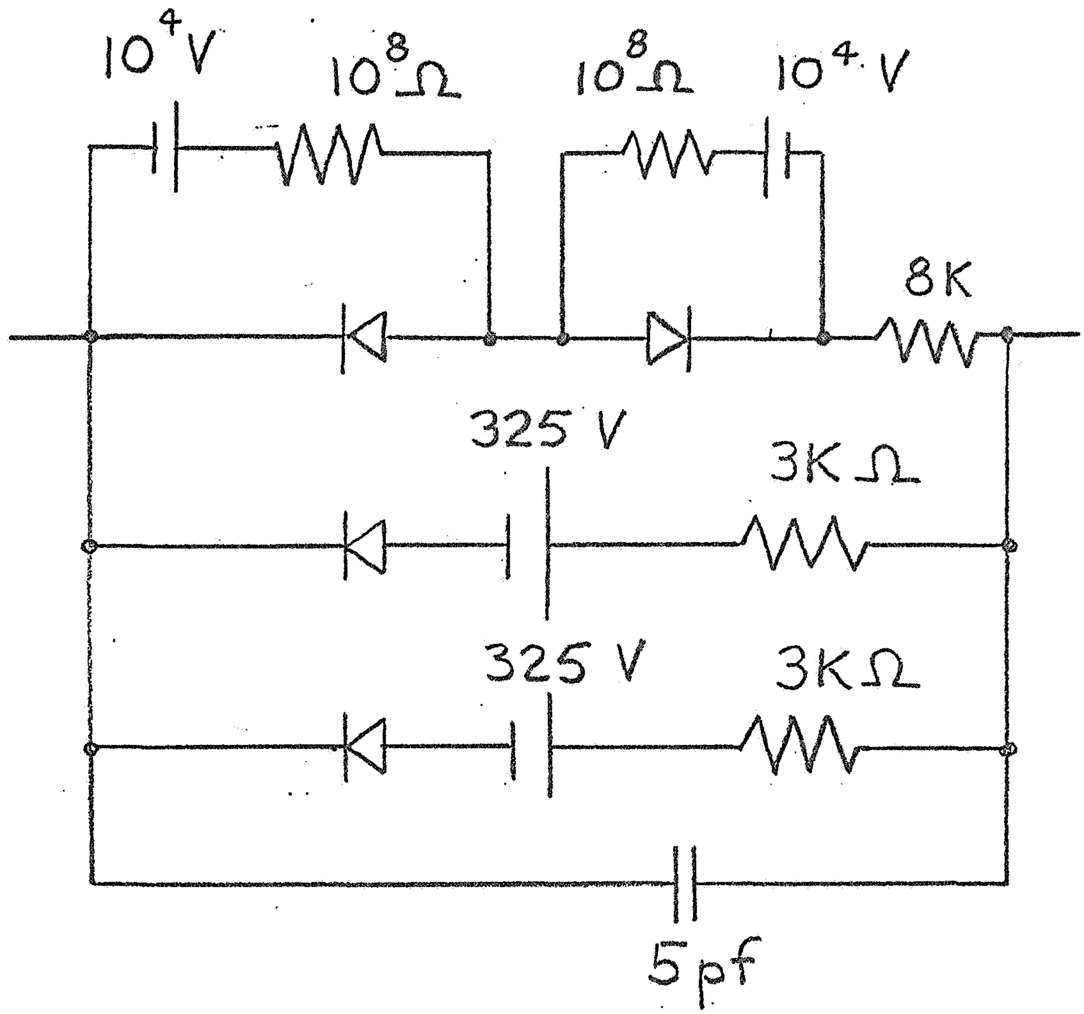


FIG. 4 TYPICAL BGLS CHARACTERISTIC CURVE

FIG. 5



TYPICAL BGLS EQUIVALENT CIRCUIT BASED ON IDEAL COMPONENTS

5.0 DESTRUCTIVE AND OTHER TESTS ON TWENTY-FIVE BREADBOARD UNITS

5.1 Overload Test Procedures

Overload tests to failure were conducted using four loading conditions as follows:

5.1.1 AC Gradual Voltage Increase Tests. A 60 Hz ac voltage was applied across the BGLS unit and the voltage was gradually increased until the unit failed. This test was also conducted for pairs of BGLS units connected in series.

5.1.2 AC Step Increment Tests. 60 Hz ac voltage was initially set to 200 v RMS and then switched across the BGLS unit. The BGLS unit was then switched out of the circuit, the voltage was increased by 10 volts, and the BGLS unit was again switched into the circuit. This process of increasing the test voltage was continued until the BGLS unit failed.

5.1.3 DC Gradual Increase Tests. A dc voltage was applied across the BGLS unit and the voltage was gradually increased until the unit failed.

5.1.4 Energy Pulse Tests. A 15 pf capacitor was charged to 1,000 volts and discharged across the BGLS unit. An 18 pf capacitor was charged to 1,000 volts and discharged across the BGLS unit. This procedure was continued with capacitance values increasing by about 20% for each step until the unit failed.

5.1.5 Extended Duration Tests. A 200 VRMS 60 Hz voltage was applied across the BGLS units under test for four days. This is not an overload test, but a maximum operating load test.

5.1.6 Simulated Failure Tests. These tests were used to determine the effects of various failure modes on the device function. Components were shorted and/or open circuited and the resulting device characteristics were measured.

5.2 Results

The primary results of these BGLS breadboard tests can be summarized as follows:

5.2.1 No Failures occurred within the contractual requirement envelope. (See 5.2.7)

5.2.2 There were no significant differences in failure mode or in the overload level required for failure between units which were subjected to a gradual increase of applied voltage and those which were subjected to incrementally increasing values of applied voltage.

5.2.3 The maximum applied voltage initiates the failure, i.e., the peak voltage of the ac signal resulting in failure approximates the dc voltage resulting in failure.

5.2.4 The failure caused by overload voltage levels result in open circuit failed units. However, the indications are than the initial failure is a reduced voltage breakdown resulting in an excessive current pulse which causes a "fuse" type open circuit.

5.2.5 There is one type of damage which can cause functional destruction of the BGLS prior to its ultimate use; this is by applying an energy pulse overload. This failure mechanism can be caused by a static charge built up to a relatively high voltage (thousands of volts) and inadvertently discharged directly through the BGLS unit. Tests conducted with a 1,000 volt source and capacitors in graduated sizes indicate that relatively low energy pulse levels can degrade the high voltage protection level of the BGLS unit. For example, a 68 pf capacitor charged to 1,000 volts and discharged through BGLS breadboard unit # 08 resulted in a break down voltage reduction from greater than 300 volts to less than 10 volts.

To prevent the damaging of BGLS in this manner, it is recommended that precautions be taken to avoid exposure to static electricity discharge prior to or during application of the BGLS to the astronaut.

5.2.6 No failures resulted from extended duration tests (four days) at 200 v RMS, 60 Hz for four units (# 6, 7, 12, 13).

5.2.7 Tabulation of Results

Breadboard BGLS Serial No.	Failure Overload	Failure Mode
16	240 v RMS 60 Hz (Gradual)	Open*
17	243 v RMS 60 Hz	Open
18	244 v RMS 60 Hz	Open
22 - 23 (in series)	500 v RMS 60 Hz (Gradual)	Open
24 - 25 (in series)	478 v RMS 60 Hz (Gradual)	Open
19	260 v RMS 60 Hz (10v Steps)	Open
20	260 v RMS 60 Hz	Open
21	250 v RMS 60 Hz	Open
8 (Encapsulated)	68 pf at 1000 v	Reduced breakdown voltage 1[illegible]
10 (Encapsulated)	37 pf at 1000 v	Reduced breakdown voltage 3[illegible]
14	100 pf at 1000 v	Reduced breakdown voltage 1[illegible]
15	270 pf at 1000 v	Reduced breakdown voltage 1[illegible]

Extended Duration Test

6	200 v 60 Hz for four days	No failure
7	200 v 60 Hz for four days	No failure
12	200 v 60 Hz for four days	No failure
13	200 v 60 Hz for four days	No failure

Extended Duration Test Continued

Breadboard BGLS Serial No.	Failure Overload
11	Simulated Failure Tests
26	Simulated Failure Tests
27	Simulated Failure Tests
28	Simulated Failure Tests
29	Simulated Failure Tests
30	Simulated Failure Tests
31	Simulated Failure Tests

*Analysis of the failed components indicates an initial short or reduced breakdown failure, followed immediately by a "fuse" type open circuit.

5.3 Recommendations

5.3.1 A method of protecting the BGLS from static discharge failures should be employed. Essentially, this consists of grounding (or insulating) equipment and personnel handling the BGLS.

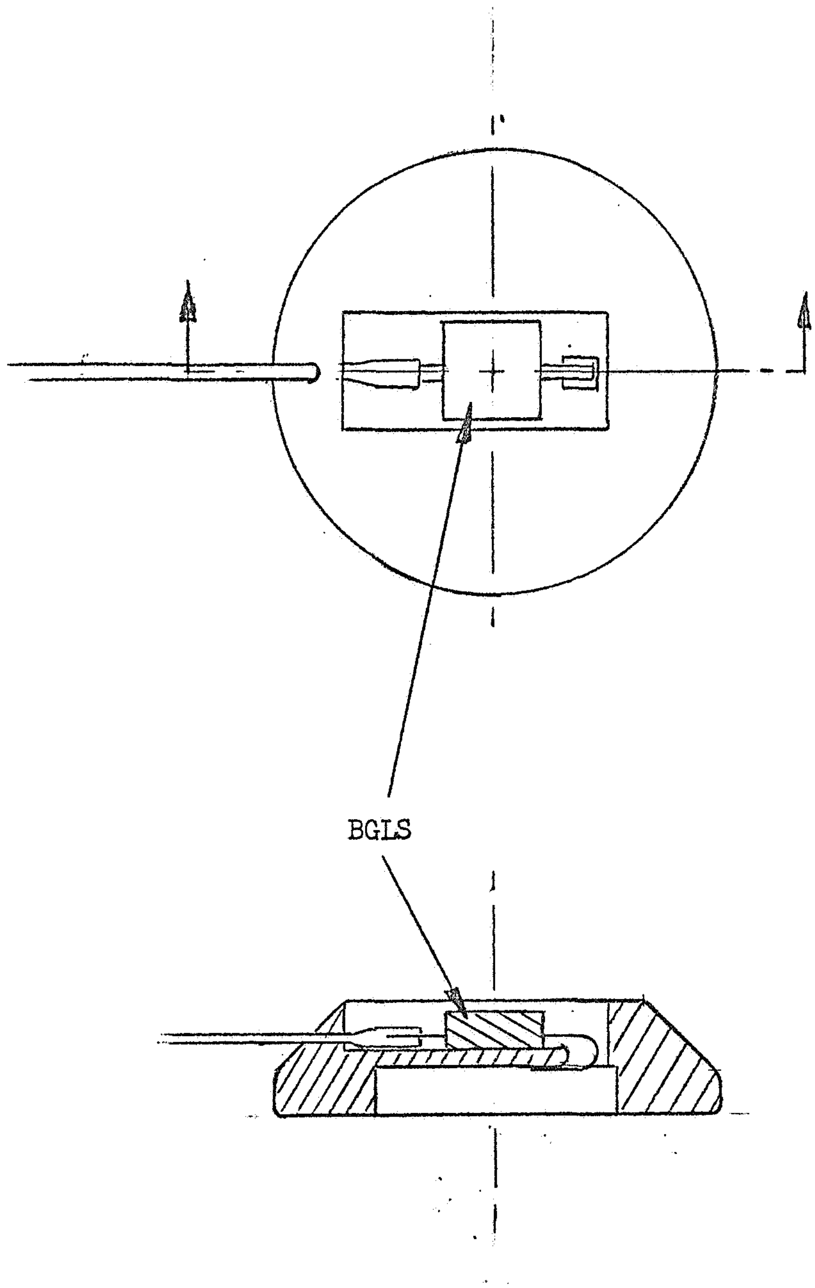
5.3.2 A simple go-no go test unit should be developed for routine use in checking BGLS units until more operating experience has been accumulated.

6.0 FUTURE REQUIREMENTS

If NASA deems the BGLS Engineering Prototype configuration to be small enough, it could be used for the flight version in a manned illustrated in Figure 6 . This shows a ground electrode having a rectangular recessed area on the side away from the skin. The BGLS could be encapsulated into this recessed area, and one lead would be routed to the electrolyte on the skin side while the other lead would be greater than a normal ground electrode unless the depth of the electrolyte paste depression could be reduced.

If further miniaturization is required, LMSC recommends that a special flatpack could be made to our specifications, to reduce the one quarter inch width.

FIG. 6



BGLS INTEGRATED INTO GROUND ELECTRODE

To enable handling personnel to check BGLS units to verify that they are in good operating condition, a simple "go or no go" test unit should be developed.

As mentioned in Section 5.0, the BGLS can be incapacitated by discharge of very high voltages through the unit prior to or during application to the astronaut. Although the probability of this occurrence is small, it may be desirable to investigate the feasibility of adding components to the internal BGLS circuit to make it invulnerable to this type of damage.